PHENIX Beam Use Efficiency & Data Acquisition and Trigger Plans

J. Nagle, University of Colorado

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- **The PHENIX and STAR collaborations should perform an evaluation to improve the ratio of data recorded with respect to delivered beam luminosity. All factors should be analyzed, including the efficiency of detector operations. This evaluation and planned actions should be documented in a report submitted to DOE by May 31, 2008 and presented at the 2008 RHIC S&T Review.**

Answers to your Questions

1. Why does PHENIX utilize only ~ 25-30% of the "delivered luminosity" for physics?

2. What steps can (and are) being taken to improve delivered luminosity → recorded physics data?

3. What resources are necessary to realize these goals?

* Note that this is a short presentation. Every item in this talk is backed up by quantitative analysis, which can be discussed in detail upon request.

Why does PHENIX utilize only ~ 25-30% of the "delivered luminosity" for physics?

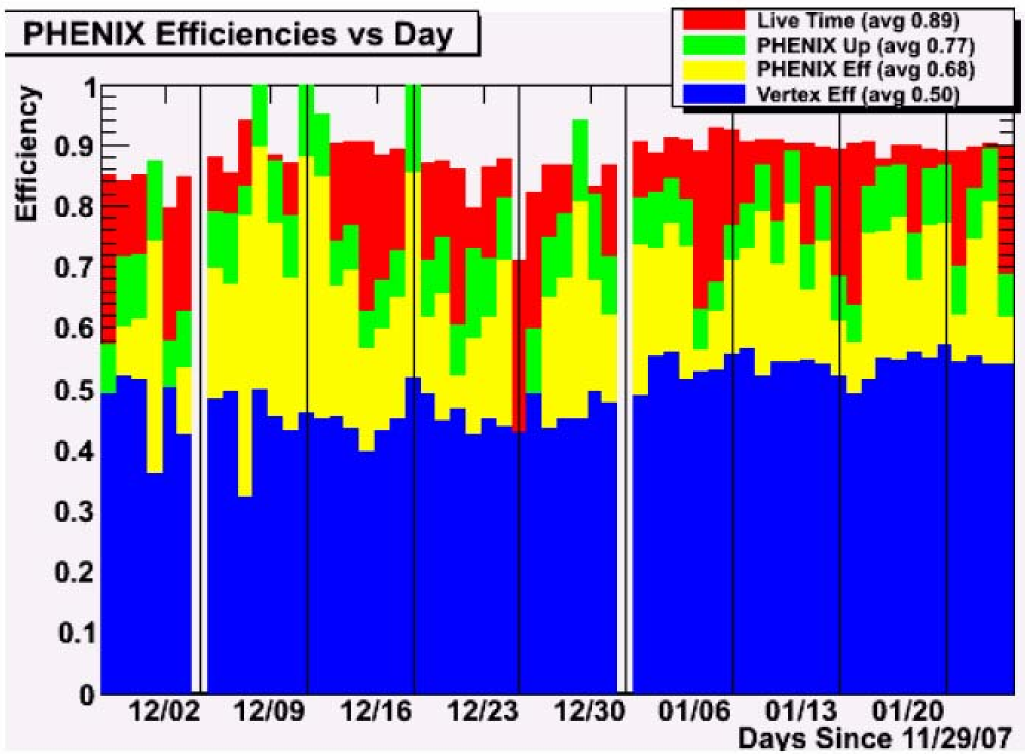
	Year	2007	2007 (last 2 wks)	2008	2008
	Species	Au+Au	Au+Au	d+Au	p+p
(A)	|z|<30 cm Eff	~50%	~50%	~50%	~50%
(B)	Uptime	64%	72%	77%	69%
(C)	Livetime	**82%**	**90%**	**89%**	**89%**
	Overall	26%	32%	34%	31%

Discuss (A), (B), and (C) in order….

Note that (C) represents the performance of the PHENIX DAQ and Triggers. We will specifically detail the Au+Au 82% and p+p 89% livetime values.

Note that these numbers are from a *detailed accounting* (done by Mike Leitch, PHENIX Run Coordinator).

These are tracked for every day during the running period.



(C) PHX Livetime

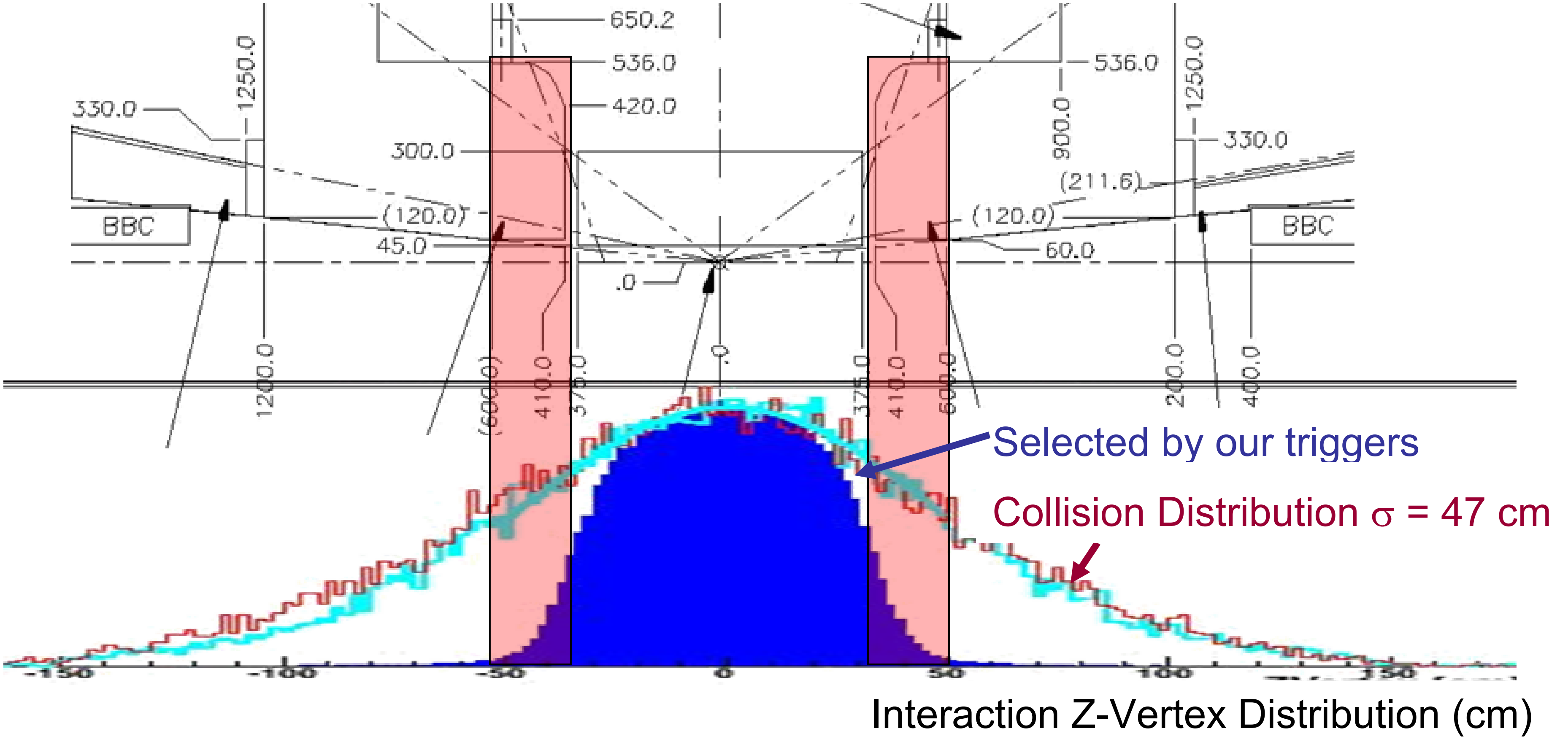
(B) PHX Uptime

PHX Eff. = (C) x (B)

(A) Z-Vertex Eff.

Figure 10. Efficiencies vs. day during the 2008 d+Au run. The product of the live time (red) and the PHENIX Up time (green) give the overall PHENIX efficiency (yellow). See luminosity weighted averages in the legend on the figure. The ratio of useful luminosity with vertex inside ±30 cm and total delivered luminosity is shown in blue.

(A) Z Vertex Efficiency



PHENIX only has acceptance for z within ± 30 cm due to Magnet Pole Tips

→ This was in accordance with original RHIC specification zvertex σ = 22 cm

Collisions have σ ~ 50 cm, and thus only ~50% within PHENIX Acceptance.

CAD projects that in 2009 with full Voltage on 200 MHz storage cavities and longitudinal stochastic cooling, zvertex σ = 20 cm, thus having 86% of interactions with ±30 cm window.

Electron cooling projections had 84% of interactions within ±10 cm.

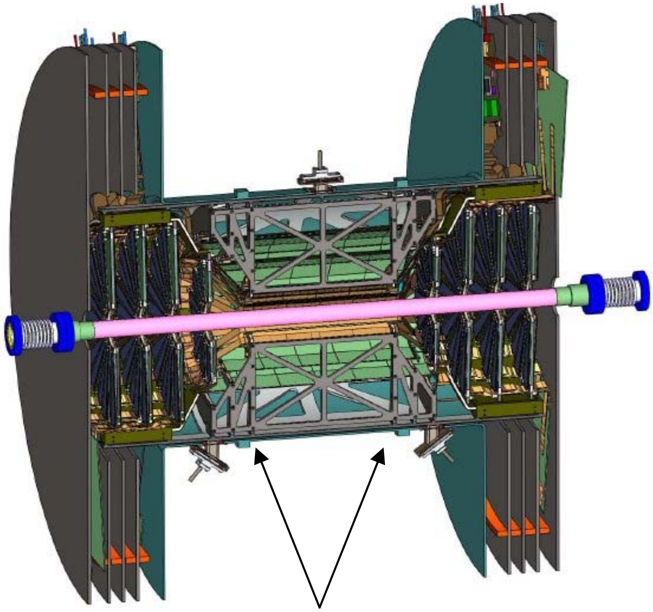
Silicon upgrades to PHENIX (and STAR) spec'ed to utilize collisions within ±10 cm.

However, with stochastic cooling only 50% of interactions within ±10 cm.

Subset of PHENIX measurements can still utilize ±30 cm (e.g. $J/\psi \rightarrow \mu\mu$).

New BBC Level-1 trigger with multiple z-vertex cut capability is being designed.

CAD is already looking into options to address this issue.



Support Structures at zvertex ±11 cm

(B) Uptime Efficiency

"Uptime" is defined as the fraction of delivered "cogged/steered/collimated" luminosity when the PHENIX detector and DAQ are taking data.

Year	2007	2007 (last 2 wks)	2008	2008
Species	Au+Au	Au+Au	d+Au	p+p
Uptime	64%	72%	77%	69%

Contributing factors and plans for improvement

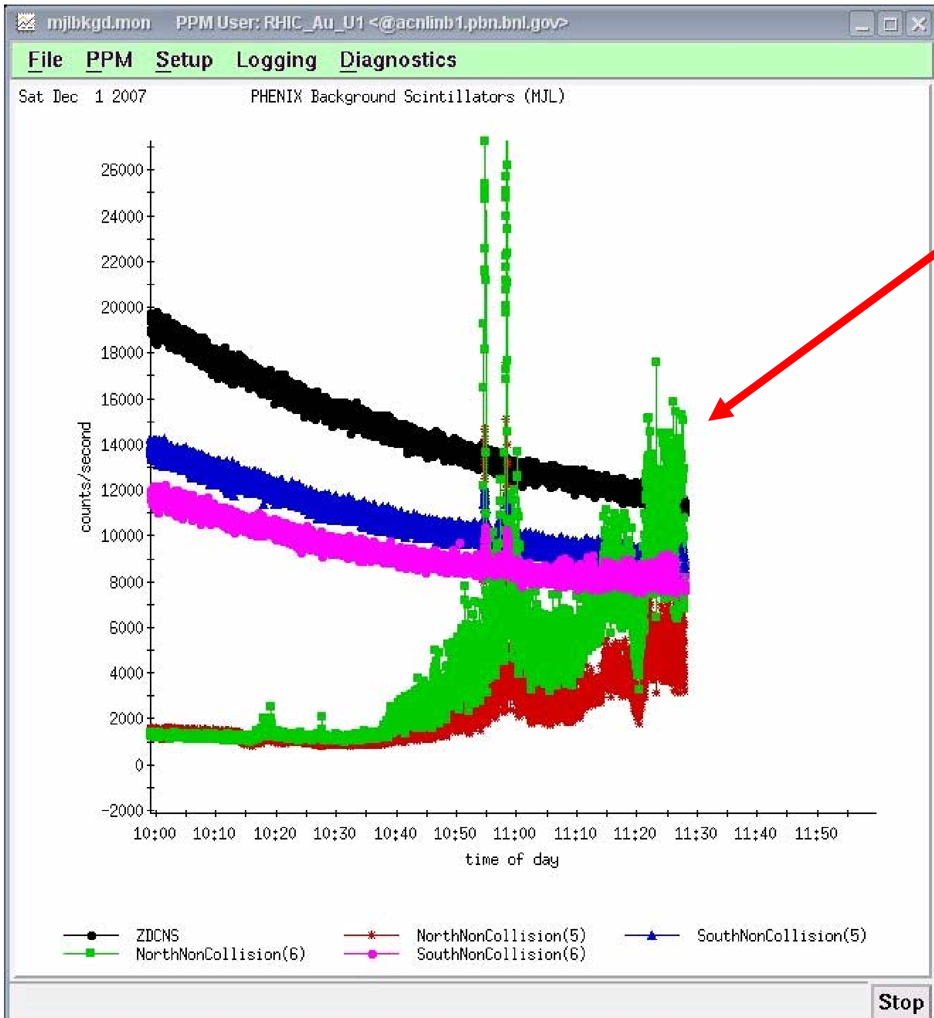
1. Note that PHENIX devotes some fraction of beam-time for trigger setup, detector configuration and testing, DAQ debugging. These are not factored out separately and decrease the uptime.

2. New detector integration results in decreased uptime (e.g. HBD in 2007 Au+Au). Multiple new detectors incorporated in the near future. PHENIX can run subsystems in separate partitions. Plans to optimize this integration underway.

3. PHENIX High Voltages cannot be turned on until beam backgrounds are at "safe" levels to avoid trips and damage to detectors. Same issue for beam dumps. PHENIX is working to optimize the Voltage turn on time, without safety risk (see next slide for example).

PHENIX has a set of scintillators to monitor beam related backgrounds.

PHENIX cannot turn all detector high Voltages on until backgrounds below levels that trip the chambers. Frequent chamber trips is a long term risk to equipment.



Particular example of high background store during early stochastic cooling.

The same issue is true of ramping off high Voltage before dumping the store.

(C) Livetime Efficiency

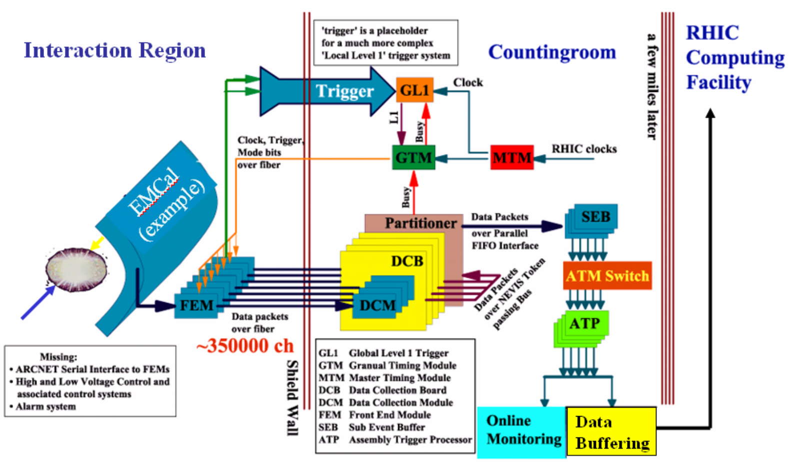
"Livetime" is defined as the fraction of delivered luminosity sampled by the PHENIX Level-1 triggers when the DAQ is running.

Year	2007	2007 (last 2 wks)	2008	2008
Species	Au+Au	Au+Au	d+Au	p+p
Livetime	**82%**	**90%**	**89%**	**89%**

PHENIX has a fully pipelined "deadtimeless" DAQ (+Front End Electronics and Triggers).

Similar to CDF,D0 (with slower clock) and ATLAS, CMS (with faster clock).

Thus, we can run at close to Level-1 trigger capacity at very high livetime.



Level-1 triggers: Interaction triggers (BBC, ZDC)
Muon triggers (MuID)
Photon triggers (EM Calorimeter)
Electron triggers (EM Calorimeter + RICH)

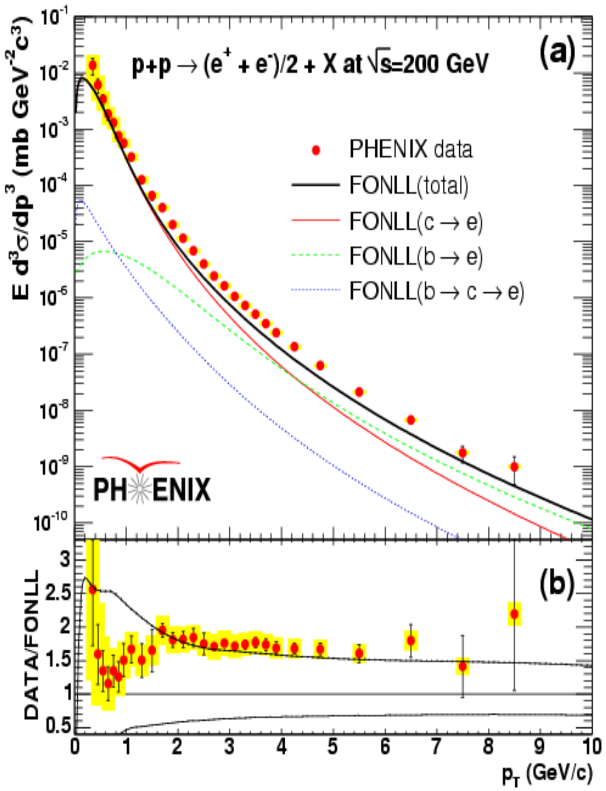
Proton-Proton Strategy

Interaction rates ~ 200-400 kHz

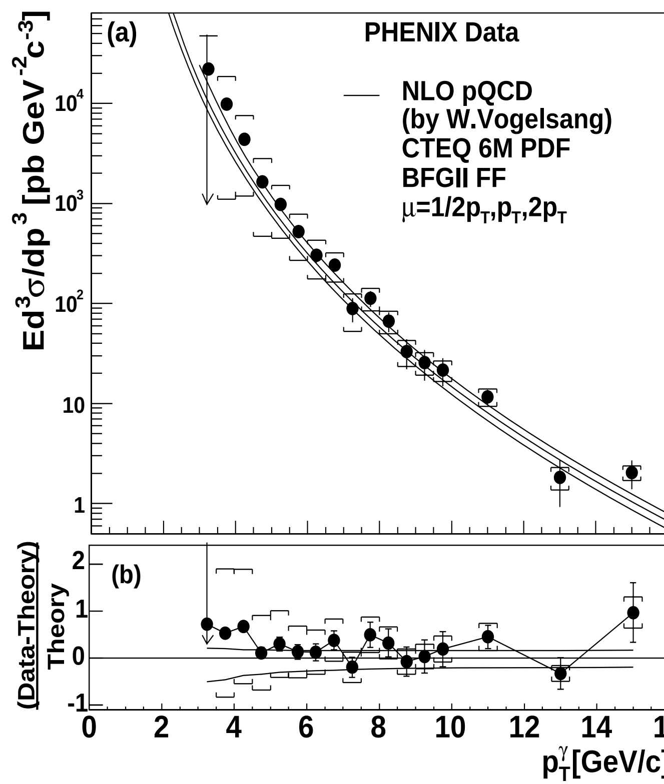
Selective Level-1 triggers reduce rate to ~ 6 kHz total, **livetime ~ 90%**

Event size ~ 100 kB → data rate through EvB ~ 600 MBytes/second

Effectively sampling luminosity for all rare channels (photons, electrons, muons)



Non-Photonic Electrons: PRL 97, 252002



Direct Photons: PRL 98, 012002

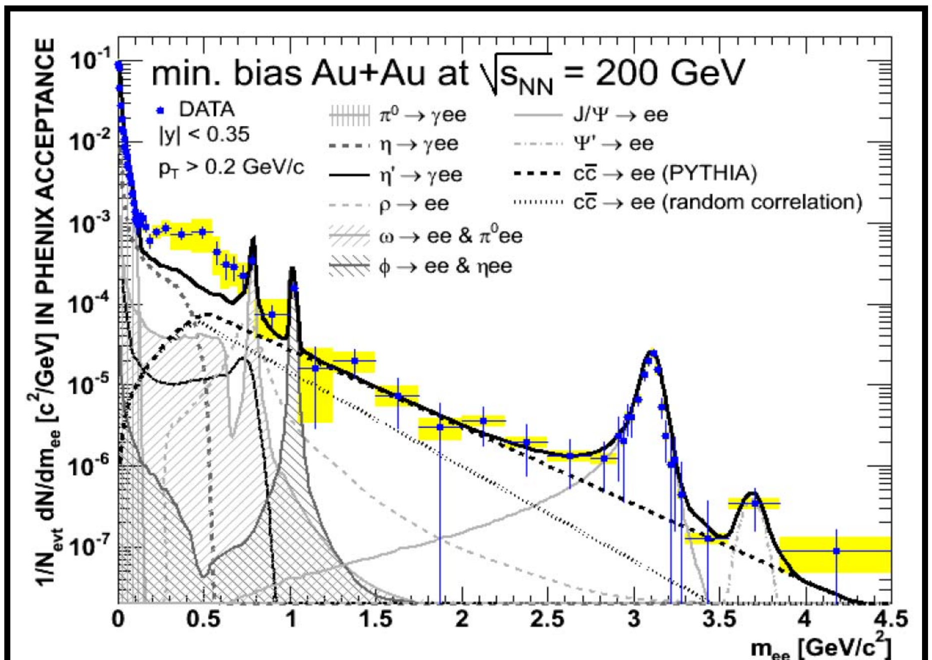
Gold-Gold Strategy

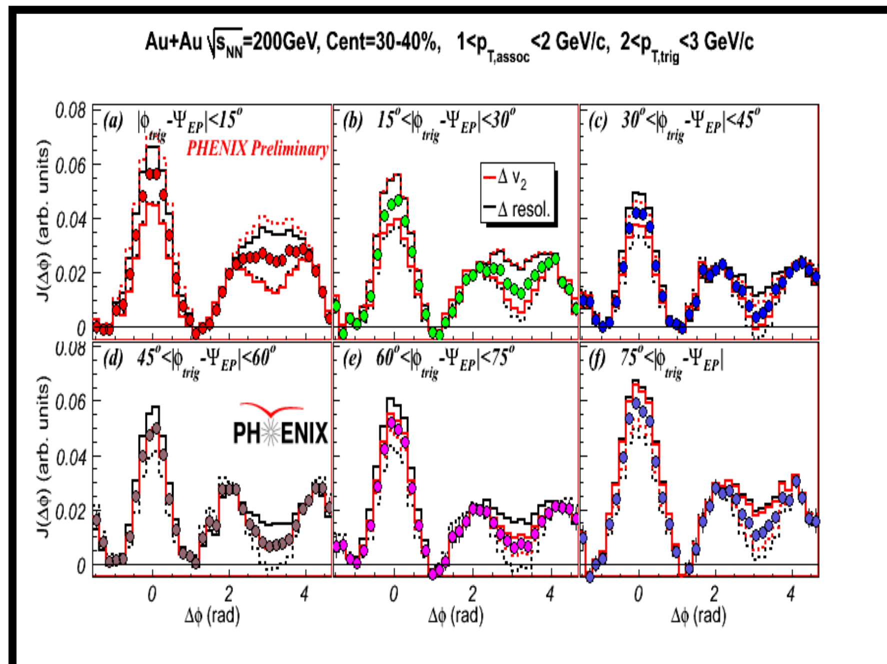
Interaction rates ~ 1 → 7 kHz (latter achieved in Run-07)

Substantial (i.e. Herculean) DAQ efforts achieved 5 kHz bandwidth/archive rate
Event size ~ 250 kB → data rate through EvB ~ 750 MBytes/second

Run-07 strategy → **record 80%** of every single interaction (all centralities)

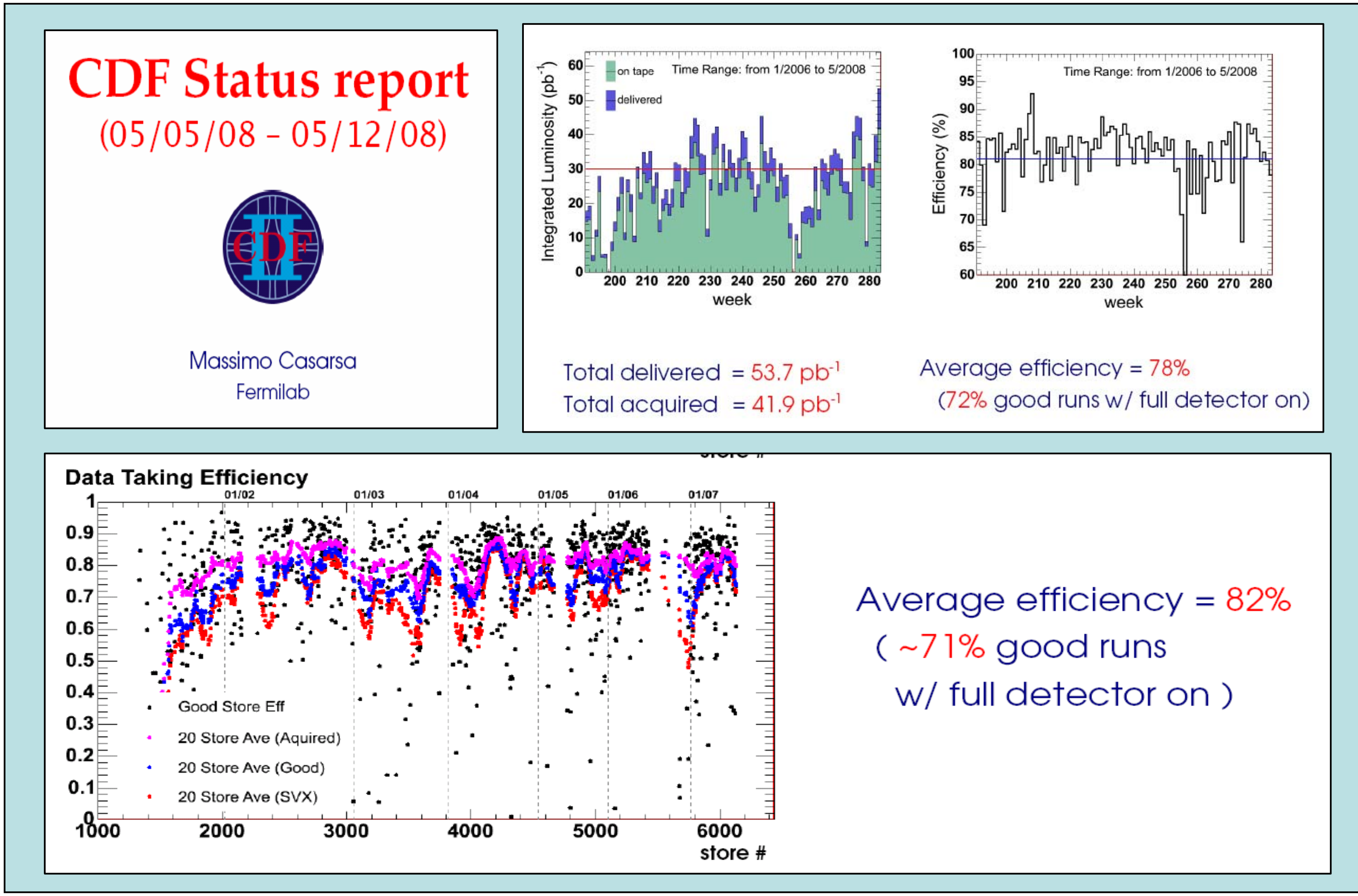
All physics channels, all centralities with 80% of maximum possible statistics recorded with no trigger efficiencies or systematics.





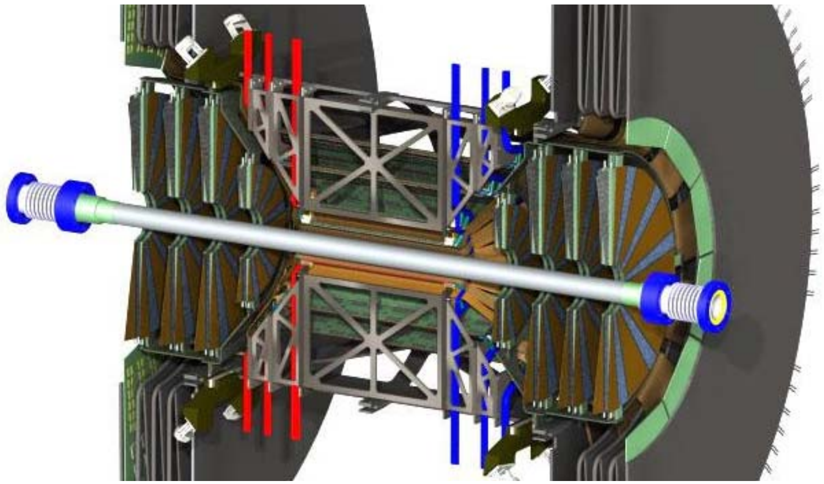
* Note that almost no rejection for low mass dielectrons and low p_T hadrons

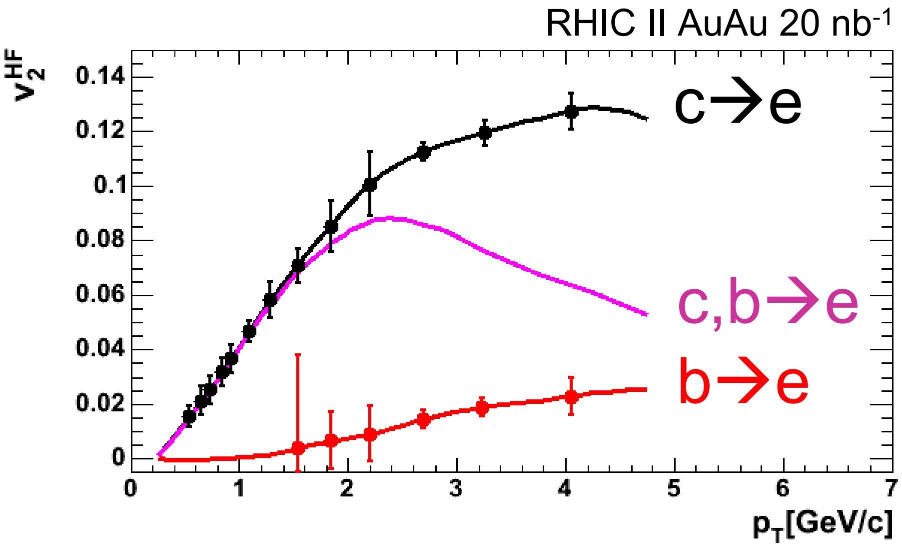
PHENIX "Efficiency" is comparable with other complex high-energy collider experiments.

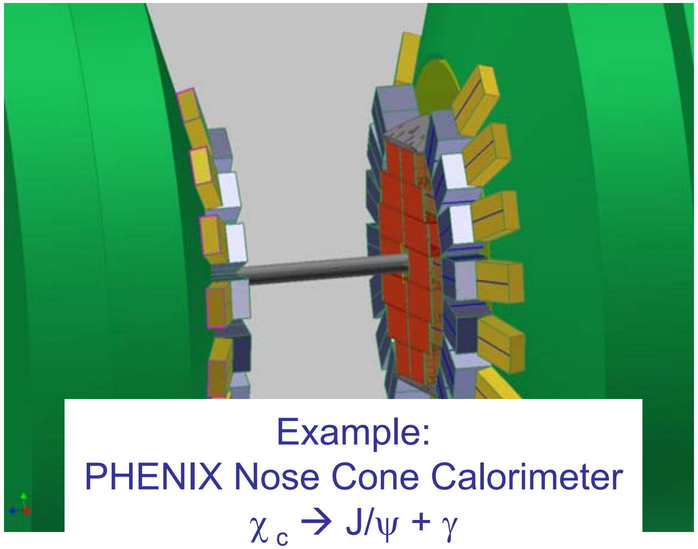


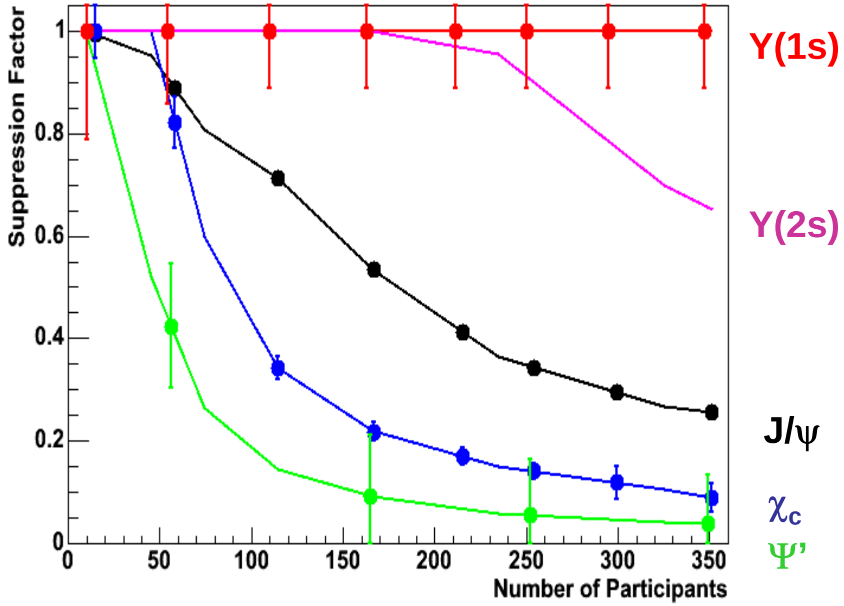
Note that maximum efficiencies are typically achieved during long running periods with stable conditions - RHIC has not been blessed with many such periods, especially compared to FNAL's multi-year running.

Future Challenges …. New Detectors → New Physics









New detectors have large data volumes…
e.g. vertex silicon pixels, 90 kBytes/event, data rate at 8 kHz → **5.8 Gigabits/second**.

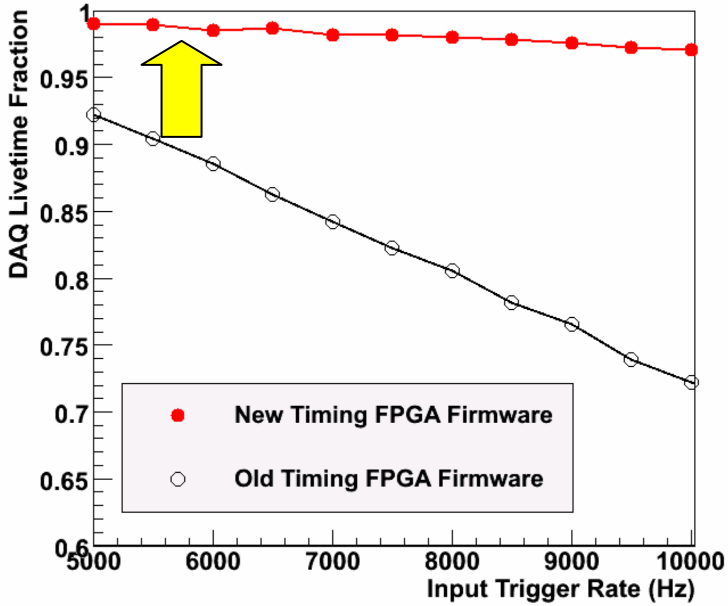
Plans to maintain high DAQ + Trigger Livetime

- New FPGA firmware for timing system (tested in Run-08, in for Run-09)

Should improve p-p livetime 90% → 97%

- New FPGA zero suppression schemes (tested in Run-08, in for Run-09)

- Other improvements underway



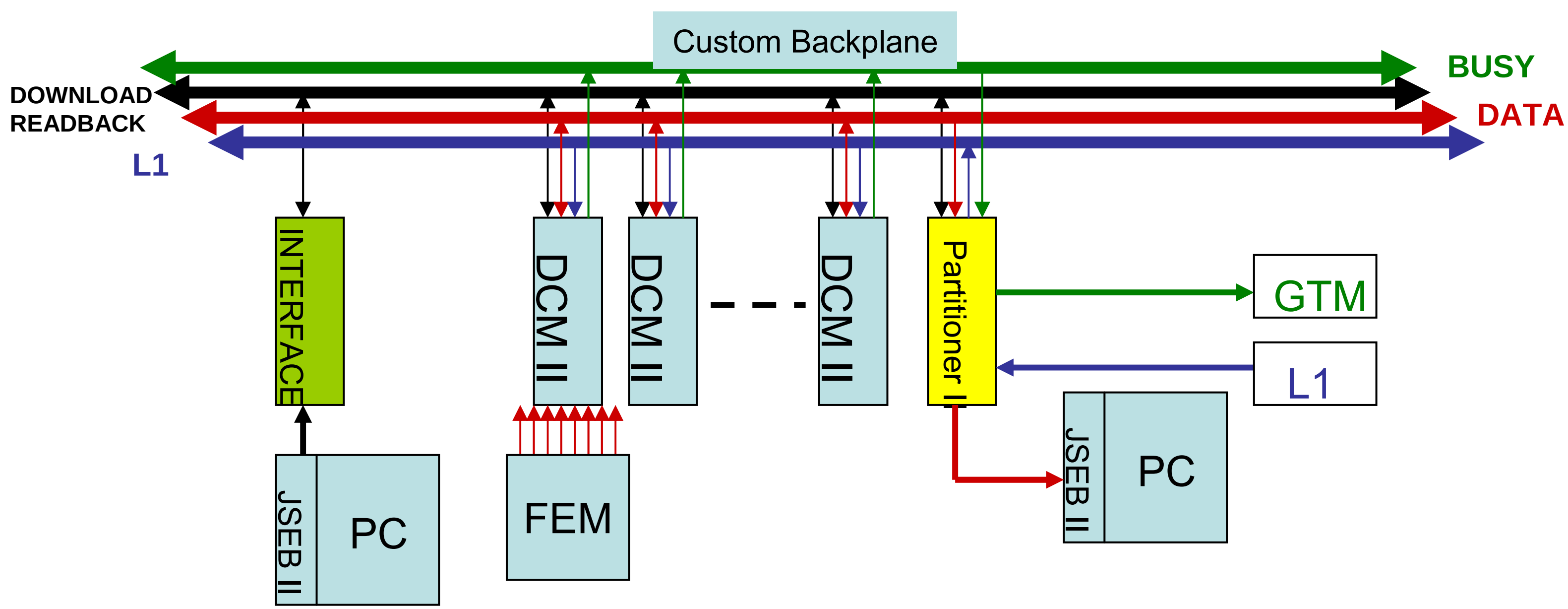
- However, without significant new DAQ hardware for new, large data volume detectors, Level-1 capacity rates will drop down to 2 kHz !

Data Collection Modules II + jSEB II necessary (see next slide)

Evolve Event Builder to 10 Gigabit capacity necessary (and to data buffering boxes).

System	Groups	Event Size	Data Rate per Group
VTX Pixel	3	90 kB	1.9 Gb/s
VTX Strip	2	39 kB	1.3 Gb/s
FVTX	6	100 kB	1.1 Gb/s
NCC	2	32 kB	1.0 Gb/s

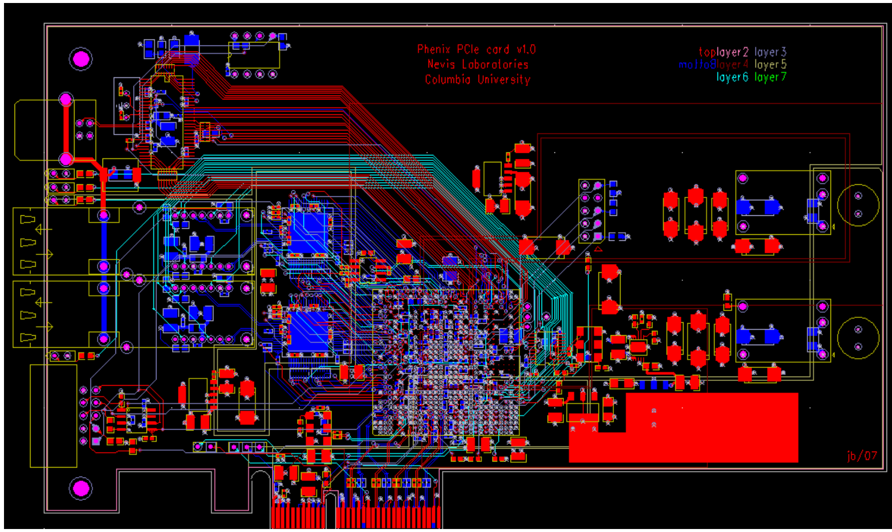
DCM II System Diagram



- Readout for all new detectors FEE

- High speed capable of full Level-1 bandwidth readout of large data volumes

- Nevis Laboratories/Colorado U.

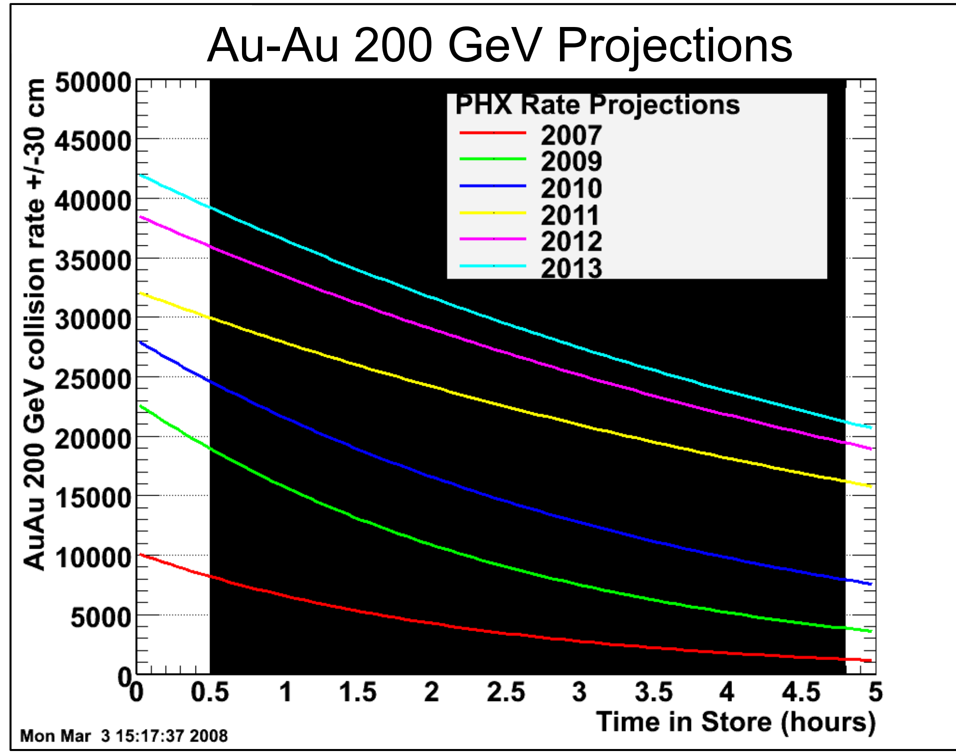


Future Challenges …. High Luminosity → New Physics

Previous strategy of recording almost all Minimum Bias Au-Au interactions will not keep pace with luminosity.

Need selective Level-1 triggers.

Year	DAQ L1 Rate 4.5 kHz
2007	86%
2009	48%
2010	31%
2011	20%
2012	17%
2013	16%



- High p_T photons/electrons will be selected with higher threshold EMCal Level-1 trigger
- Dimuons (J/ψ, Υ) needs Level-1 selection improvement → 2-dimensional muon roads
- Moderate p_T electrons and J/ψ → ee, Level-1 trigger studies underway

Future Challenges …. High Luminosity → New Physics

Proton-Proton @ 200, 500 GeV → rates ~ 7 MHz projected
w/ existing Level-1 triggers needs bandwidth < 1k for each

Trigger	Current Rejections	Bandwidth
MUID1D1S (N)	14,000	500 Hz
MUID1D1S (S)	23,000	300 Hz
MUID1D (N)	670	10,000 Hz
MUID1D (S)	950	7,700 Hz
ERT4x4B (2.9 GeV)	3100	2,200 Hz
ERT4x4A (2.1 GeV)	926	7,500 Hz
ERT_Elec	190	36,000 Hz

e.g. J/ψ, $\Psi \rightarrow \mu\mu$

In good shape

e.g. $W \rightarrow \mu$

W trigger upgrades to address (NSF, DOE, JPS)

e.g. high p_T π^0, γ

Adjust thresholds

e.g. low p_T electrons, $J/\psi \rightarrow ee$

EMCal trigger improvement R&D needed

Data Acquisition Projects

Project	Groups	Development Cost (approx.)	Goal	Implementation Cost (approx.)
DCM II + jSEB II	Nevis, Colorado	$420k	High bandwidth readout of new subsystems	Board costs in upgrade budgets
Event Builder + Network Upgrades	Columbia, BNL	$60k	Develop 10 Gigabit network systems	Full system ~ $500k
Buffer boxes	BNL	$50k	Increase data recording capacity	Full system ~ $250 k
Upgraded DCM daughter cards	BNL, SUNYSB, Nevis, Colorado	$20k	Investigate improvement in FPGA comp.	No estimate yet. Pending R&D.
Demultiplexing	BNL, ORNL	$10k	Test setup to investigate speed doubling option	No estimate yet. Pending R&D.

Total is ~ $400k/year over the next three-four years.

Trigger Projects

Project	Groups	Development Cost (approx.)	Goal	Implementation Cost (approx.)
BBC w/ multiple vertex selections	ISU, Nevis	--	Level-1 trigger capability to select ±10 or ± 30 cm	$50k
MuID Trigger FPGA Upgrade	ISU	--	Allow 2-D muon road finding	Institutional Contribution
VTX Interaction Trigger	ISU, ORNL, BNL	$25k	Develop VTX pixel interaction trigger (for pp and low energy)	No estimate yet. Pending R&D.
Electron/Photon Trigger Upgrade*	Nevis, Colorado, BNL	$25k	Engineering support to test new calorimeter electronics	No estimate yet. Of order $2M
W→muon Trigger Upgrades	ACU, BNL, UCR, CIAE, Colorado, Columbia, GSU, UIUC, ISU, KEK, Korea U. Kyoto, LANL, Muhlenberg, UNM, Peking, RIKEN, Rikkyo			Already funded from NSF, DOE, JPS

* PHENIX is just in an R&D phase and after completed, discussion of possible funding sources needed.

Summary

PHENIX has undergone continuous bandwidth growth from Run-01 through Run-08. No other collider detector has ever done this. The DAQ has kept pace with this, and now performs at ~30 times the original spec of 20 MB/s.

We have improved our efficiencies in the past couple of years, and have a few more small tricks up our sleeve.

However, the next steps require bigger effort, termed DAQTRIG2010.

DAQTRIG2010 Institutions: BNL, Colorado, Columbia (Nevis Laboratories), ISU

Key components include:

1. DAQ (DCM II + EvB @ 10 Gigabit + ↑Buffer Boxes) for reading out new, high data volume detectors at large bandwidth.

2. Trigger upgrades to handle very high p-p @ 200, 500 GeV luminosity, and utilization of rare triggers in Au-Au reactions.

BACKUP

1984 BNL-51801: RHIC "Blue Book" "RHIC and Quark Matter" specifies a vertex rms for 200 GeV Au+Au as 35 cm (at injection) to 106 cm (after 10 hour store).

Elsewhere in this report the loss of beam from ions spilling out of the bucket is estimated to be 15% at the end of a 10 hour full energy Au+Au store.

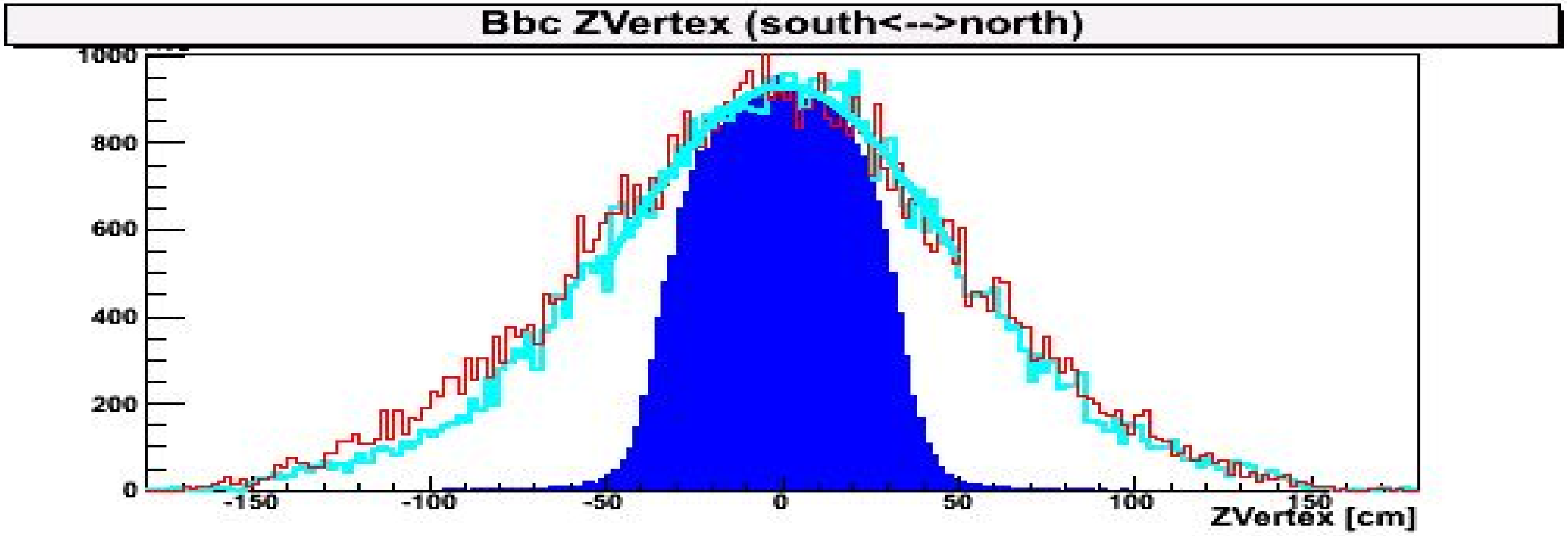
1985 BNL-51921: "RHIC Workshop- Experiments for a Relativistic heavy Ion Collider" is consistent with the 1984 assumptions, see especially that article 'Machine Perspective: How to Work with RHIC' by our own Glenn Young.

1986 BNL-51932: "Conceptual Design of the Relativistic Heavy Ion Collider RHIC" has identically the same text and spec for the vertex rms as the 1984 Blue Book.

1988 BNL-52185: "Proceedings of the 3rd Workshop on Experiments and Detectors for a Relativistic Heavy Ion Collider (RHIC)", has an article 'The RHIC Project: Overview and Status' by H. Hahn. In this article one reads "A number of experiments call for a diamond length of \leq 20 cm rms.", followed by a discussion of the requirements for a *storage* RF system which provides a vertex rms of (Bunch Length)/sqrt{2} = (31 cm)/sqrt{2} = 22 cm.

What changed between 1986 and 1988 is that a 160 MHz storage RF system with the somewhat ambitious voltage requirement in excess of 10 MV was added to the 27 MHz acceleration RF system.

Run #257510 Events: 191223 Date:Sat Feb 23 07:11:14 2008



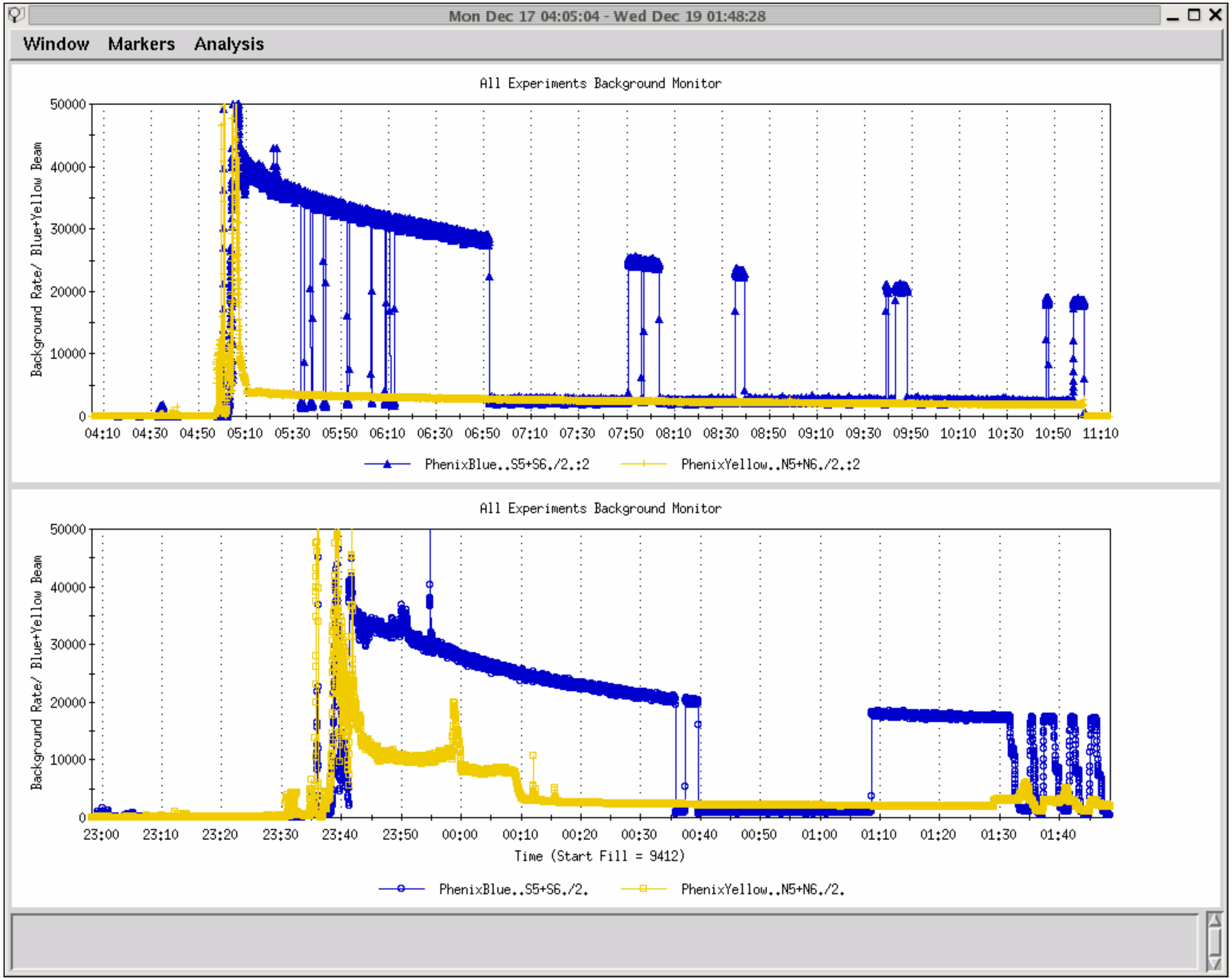
$Z^{Fit}_{BBLL1\ w/o\ Vtx}$ = 0.4 cm (σ = 47 cm) ... OK

Z [Trigger]	Zbbc [BBLL1]	Zzdc [ZDCLL1wide]	Zbbc [BBCLL1(noVtxCut)]
(Scale Fac.) #Evt.	(201) 147927	(56) 21729	(2701) 21324

< Each histograms are scaled by scaled factor.>

Vertex Mean (RMS)	-0.6cm (21.5 cm)	-3.9cm (54.4 cm)	-0.3cm (50.6 cm)

σ_{ZDC} = 0.004 ϵ_{BBC} = 0.004 $\frac{\text{beam in acceptance}}{\text{ZDC}}$ = 0.097 $\frac{\text{beam in acceptance}}{\text{BBC}}$ = 0.525



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Window
Markers
Analysis
All Experiments Background Monitor
Background Rate/ Blue+Yellow Beam
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PhenixBlue..S5+S6./2.:2
PhenixYellow..N5+N6./2.:2
All Experiments Background Monitor
Background Rate/ Blue+Yellow Beam
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Time (Start Fill = 9412)
PhenixBlue..S5+S6./2.
PhenixYellow..N5+N6./2.